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LIMITS OF HUMAN EXPOSURE TO RADIOFREQUENCY ELECTROMAGNETIC ENERGY IN THE FREQUENCY RANGE FROM 3 KHZ TO 300 GHZ

Consumer and Clinical Radiation Protection Bureau
Environmental and Radiation Health Sciences Directorate
Healthy Environments and Consumer Safety Branch
Health Canada

SAFETY CODE 6 (2015)

Canada

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Limites d'exposition humaine à l'énergie électromagnétique radioélectrique dans la gamme de fréquences de 3 kHz à 300 GHz

To obtain additional information, please contact:

Health Canada
Address Locator 0900C2
Ottawa, ON K1A 0K9
Tel.: 613-957-2991
Toll free: 1-866-225-0709
Fax: 613-941-5366
TTY: 1-800-465-7735
E-mail: publications@hc-sc.gc.ca

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PREFACE

This document is one of a series of safety codes prepared by the Consumer and Clinical Radiation Protection Bureau, Health Canada. These safety codes specify the requirements for the safe use of, or exposure to, radiation emitting devices. This revision replaces the previous version of Safety Code 6 (2009).

The purpose of this code is to establish safety limits for human exposure to radiofrequency (RF) fields in the frequency range from 3 kHz to 300 GHz. The safety limits in this code apply to all individuals working at, or visiting, federally regulated sites. These guidelines may also be adopted by the provinces, industry or other interested parties. The Department of National Defence shall conform to the requirements of this safety code, except in such cases where it considers such compliance to have a detrimental effect on its activities in support of training and operations of the Canadian Forces. This code has been adopted as the scientific basis for equipment certification and RF field exposure compliance specifications outlined in Industry Canada's regulatory documents (1–3), that govern the use of wireless devices in Canada, such as cell phones, cell towers (base stations) and broadcast antennas. Safety Code 6 does not apply to the deliberate exposure for treatment of patients by, or under the direction of, medical practitioners. Safety Code 6 is not intended for use as a product performance specification document, as the limits in this safety code are for controlling human exposure and are independent of the source of RF energy.

In a field where technology is advancing rapidly and where unexpected and unique exposure scenarios may occur, this code cannot cover all possible situations. Consequently, the specifications in this code may require interpretation under special circumstances. This interpretation should be done in consultation with scientific staff at the Consumer and Clinical Radiation Protection Bureau, Health Canada.

The safety limits in this code are based on an ongoing review of published scientific studies on the health impacts of RF energy and how it interacts with the human body. This code is periodically revised to reflect new knowledge in the scientific literature and the exposure limits may be modified, if deemed necessary.

TABLE OF CONTENTS

PREFACE I

1. INTRODUCTION 1

1.1 Purpose of the code 2

2. MAXIMUM EXPOSURE LIMITS 2

2.1 Basic Restrictions 4

2.1.1 Internal Electric Field Strength Limits (3 kHz–10 MHz) 4

2.1.2 Specific Absorption Rate Limits (100 kHz–6 GHz) 5

2.1.3 Frequencies from 6 GHz–300 GHz 5

2.2 Reference Levels 6

2.2.1 Electric and Magnetic Field Strength (3 kHz–10 MHz) 6

2.2.2 Electric Field Strength, Magnetic Field Strength and Power Density (10 MHz–300 GHz) 8

2.2.3 Induced and Contact Current (3 kHz–110 MHz) 10

ABBREVIATIONS 12

DEFINITIONS 13

REFERENCES 15

1. INTRODUCTION

Electromagnetic radiation is emitted by many natural and man-made sources and is a fundamental aspect of our lives. We are warmed by electromagnetic radiation emitted from the sun and our eyes can detect the visible light portion of the electromagnetic spectrum. Radiofrequency (RF) fields fall within a portion of the electromagnetic spectrum with frequencies ranging from 3 kHz to 300 GHz, below that of visible light and above that of extremely low frequency electromagnetic fields. RF fields are produced by many man-made sources including cellular (mobile) phones and base stations, television and radio broadcasting facilities, radar, medical equipment, microwave ovens, RF induction heaters as well as a diverse assortment of other electronic devices within our living and working environments.

A number of biological effects and established adverse health effects from acute exposure to RF fields have been documented (4–9). These effects relate to localized heating or stimulation of excitable tissue. The specific biological responses to RF fields are generally related to the rate of energy absorbed or the strength of internal electric fields (voltage gradients) and currents. The rate and distribution of RF energy absorption depend strongly on the frequency, strength and orientation of the incident fields as well as the body size and its constitutive electrical properties (dielectric constant and conductivity). Absorption of RF energy is commonly described in terms of the specific absorption rate (SAR), which is a measure of the rate of energy deposition per unit mass of body tissue and is usually expressed in units of watts per kilogram (W/kg). Based on a large amount of scientific knowledge, national and international exposure limits have been established to protect the general public against all adverse effects associated with RF field exposures (10–14).

The exposure limits specified in Safety Code 6 have been established based upon a thorough evaluation of the scientific literature related to the thermal and non-thermal health effects of RF fields. Health Canada scientists consider all peer-reviewed scientific studies, on an ongoing basis, and employ a weight-of-evidence approach when evaluating the possible health risks of exposure to RF fields. This approach takes into account the quantity of studies on a particular endpoint (whether adverse or no effect), but more importantly, the quality of those studies. Poorly conducted studies (e.g. those with incomplete dosimetry or inadequate control samples) receive relatively little weight, while properly conducted studies (e.g. all controls included, appropriate statistics, complete dosimetry) receive more weight. The exposure limits in Safety Code 6 are based upon the lowest exposure level at which any scientifically established adverse health effect occurs. Safety margins have been incorporated into the exposure limits to ensure that even worst-case exposures remain far below the threshold for harm. The scientific approach used to establish the exposure limits in Safety Code 6 is comparable to that employed by other science-based international standards bodies (15–16). As such, the basic restrictions in Safety Code 6 are similar to those adopted by most other nations, since all science-based, standard-setting bodies use the same scientific data. It must be stressed that Safety Code 6 is based upon established adverse health effects and should be distinguished from some municipal and/or national guidelines that are based on socio-political considerations.

In the following sections, the maximum exposure levels for persons in both controlled and uncontrolled environments are specified. These levels shall not be exceeded.

1.1 PURPOSE OF THE CODE

The purpose of this code is to specify maximum levels of human exposure to RF fields at frequencies between 3 kHz and 300 GHz, to prevent adverse human health effects in both controlled and uncontrolled environments.

In this code, controlled environments are defined as those where all of the following conditions are satisfied:

(a) the RF field intensities in the controlled area have been adequately characterized by means of measurements or calculation,

(b) the exposure is incurred by persons who are aware of the potential for RF exposure and are cognizant of the intensity of the RF fields in their environment and,

(c) the exposure is incurred by persons who are aware of the potential health risks associated with RF field exposures and can control their risk using mitigation strategies.

Situations that do not meet all the specifications above are considered to be uncontrolled environments. Uncontrolled environments are defined as areas where either insufficient assessment of RF fields has been conducted or where persons who are allowed access to these areas have not received proper RF field awareness/safety training and have no means to assess or, if required, to mitigate their exposure to RF fields.

2. MAXIMUM EXPOSURE LIMITS

The scientific literature with respect to possible biological effects of RF fields has been monitored by Health Canada scientists on an ongoing basis. Since the last version of Safety Code 6 was published (2009), a significant number of new studies have evaluated the potential for acute and chronic RF field exposures to elicit possible effects on a wide range of biological endpoints including: human cancers; rodent lifetime mortality; tumor initiation, promotion and co-promotion; mutagenicity and DNA damage; EEG activity; memory, behaviour and cognitive functions; gene and protein expression; cardiovascular function; immune response; reproductive outcomes; and perceived electromagnetic hypersensitivity among others. Numerous authoritative reviews have summarized the current literature (4–8, 17–40).

Despite the advent of numerous additional research studies on RF fields and health, the only established adverse health effects associated with RF field exposures in the frequency range from 3 kHz to 300 GHz relate to the occurrence of tissue heating and nerve stimulation (NS) from short-term (acute) exposures. At present, there is no scientific basis for the occurrence of acute, chronic and/or cumulative adverse health risks from RF field exposure at levels below the limits outlined in Safety Code 6. The hypotheses of other proposed adverse health effects occurring at levels below the exposure limits outlined in Safety Code 6 suffer from a lack of evidence of causality, biological plausibility and reproducibility and do not provide a credible foundation for making science-based recommendations for limiting human exposures to low-intensity RF fields.

This safety code provides guidance for the avoidance of adverse human health effects resulting from exposure to RF fields, in terms of basic restrictions and/or reference levels. Basic restrictions are exposure indices within the body that should not be exceeded. These exposure indices are

directly linked to established adverse health effects. The basic restrictions in this safety code are specified in terms of: a) internal electric field strength; and b) the rate of RF energy absorption (SAR). Since measurements of the SAR or internal electric field strength are often difficult to perform, reference levels for maximum human exposure to RF fields have also been specified in this safety code. The reference levels are specified in terms of unperturbed, externally applied electric- and magnetic-field strength, power density and in terms of electric currents in the body occurring from either induction or contact with energized metallic objects. They were established using dosimetric analyses that determined the levels of externally applied field strengths that would produce the basic restrictions within the body. While compliance with the basic restrictions is required, non-compliance with the reference levels does not necessarily mean that the basic restrictions are not respected. In such cases, additional measurements or calculations may be required to assess compliance.

For frequencies from 3 kHz to 10 MHz, NS from induced electric fields within the body must be avoided. Experimental studies have demonstrated that electric and magnetic field exposures can induce internal electric fields (voltage gradients) within biological tissue which, if sufficiently intense, can alter the "resting" membrane potential of excitable tissues resulting in spontaneous depolarization of the membrane and the generation of spurious action potentials (5, 10, 11, 13, 14, 35, 41). Basic restrictions for the avoidance of NS are specified in this safety code in terms of maximum internal electric field strength within the body.

For frequencies from 100 kHz to 300 GHz, tissue heating can occur and must be limited. Basic restrictions have been specified in this safety code for RF field exposures in the 100 kHz to 6 GHz frequency range, in terms of maximum whole-body SAR (averaged over the whole-body) and peak spatially-averaged SAR, (averaged over a small cubical volume). For frequencies above 6 GHz, RF energy absorption occurs predominantly in surface tissues (e.g. upper layers of skin) and the use of maximum SAR limits, either whole-body or averaged over a cubical volume, is not appropriate. In lieu of basic restrictions, reference levels are specified for maximum unperturbed, externally applied electric- and magnetic-field strengths and in terms of power density, for the avoidance of thermal effects.

Studies in animals, including non-human primates, have consistently demonstrated a threshold effect for the occurrence of behavioural changes and alterations in core body temperature of ~1.0°C, at a whole-body average SAR of ~4 W/kg (5–8, 11, 12, 14, 36). Thermoregulatory studies in human volunteers exposed to RF fields under a variety of exposure scenarios have provided supporting information on RF field induced thermal responses in humans (42). This information forms the scientific basis for the basic restrictions on whole-body average SAR in Safety Code 6. To ensure that thermal effects are avoided, safety factors have been incorporated into the exposure limits, resulting in whole-body-averaged SAR limits of 0.08 and 0.4 W/kg in uncontrolled- and controlled-environments, respectively.

Basic restrictions on peak spatially-averaged SAR have also been established in Safety Code 6 to avoid adverse thermal effects in localized human tissues (hot-spots). The peak spatially-averaged SAR limits reflect the highly heterogeneous nature of typical RF field exposures and the differing thermoregulatory properties of various body tissues. The peak spatially-averaged SAR limits pertain to discrete tissue volumes (1 or 10 g, in the shape of a cube), where thermoregulation can efficiently dissipate heat and avoid changes in body temperature that are greater than 1°C.

As such, the peak spatially-averaged SAR limits for exposures in controlled environments are 20 W/kg for the limbs and 8 W/kg for the head, neck and trunk. For exposures in uncontrolled environments, the peak spatially-averaged SAR limits are 4.0 W/kg for the limbs and 1.6 W/kg for the head, neck and trunk.

For frequencies from 100 kHz to 10 MHz, since either NS or thermal effects could occur, depending upon the exposure conditions (frequency, duty cycle, orientation), basic restrictions for both internal electric field strength and SAR (whole-body and peak spatially-averaged) must be simultaneously respected. Safety Code 6 also specifies reference levels in the 3 kHz to 110 MHz frequency range, in terms of induced- or contact-currents (mA), for the avoidance of perception (nerve stimulation), shocks or burns (4, 6).

While the biological basis for the basic restrictions specified in this safety code has not changed since the previous version (2009), the reference levels have been updated to either account for dosimetric refinements in recent years (43–64) or where feasible, to harmonize with those of ICNIRP (10–11).

To determine whether the maximum exposure levels are exceeded, full consideration shall be given to such factors as:

(a) nature of the exposure environment (controlled or uncontrolled environment);

(b) temporal characteristics of the RF source (including ON/OFF times, duty factors, direction and sweep time of the beam, etc.);

(c) spatial characteristics between the exposure source and target (i.e. near-field exposures, whole body or parts thereof);

(d) uniformity of the exposure field (i.e. spatial averaging).

Where comparison is to be made to the SAR-based basic restrictions and/or reference levels at frequencies in the 100 kHz–300 GHz range, higher exposure levels may be permitted for short durations of time under certain circumstances. For these situations, the field strengths, power densities and body currents averaged over any one tenth-hour reference period (6 minutes) shall not exceed the limits outlined in Sections 2.1 and 2.2.

SI units are used throughout this document unless specified otherwise.

2.1 BASIC RESTRICTIONS

2.1.1 Internal Electric Field Strength Limits (3 kHz–10 MHz)

Limits for internal electric field strength are intended to prevent the occurrence of NS. At frequencies between 3 kHz and 10 MHz, basic restrictions for internal electric field strength in excitable tissues (Table 1) shall not be exceeded. For conditions where the determination of internal electric field strength is not possible or practical (e.g. by measurement or modelling), external unperturbed field strength assessment shall be carried out and the reference levels outlined in Section 2.2 shall be respected.

TABLE 1: Internal Electric Field Strength Basic Restrictions (3 kHz–10 MHz)

CONDITION	Internal Electric Field Strength (V/m) (in any excitable tissue)
Controlled Environment	$2.7 \times 10^{-4} f$
Uncontrolled Environment	$1.35 \times 10^{-4} f$

Frequency, f, is in Hz. Instantaneous, root mean square (RMS) values apply. In the case of RF fields with amplitude modulation, then RMS values during the maximum of the modulation envelope shall apply.

2.1.2 Specific Absorption Rate Limits (100 kHz–6 GHz)

The SAR is a measure of the rate at which electromagnetic energy is absorbed in the body. Basic restrictions for SAR are intended to prevent the occurrence of thermal effects from RF energy exposure on the body. At frequencies between 100 kHz and 6 GHz, the SAR limits (Table 2) take precedence over field strength and power density reference levels (Section 2.2) and shall not be exceeded.

The SAR should be determined for situations where exposures occur at a distance of 0.2 m or less from the source. In all cases, the values in Table 2 shall not be exceeded. For conditions where SAR determination is impractical, external unperturbed field strength or power density measurements shall be carried out and the limits outlined in Section 2.2 shall be respected.

TABLE 2: Specific Absorption Rate Basic Restrictions (100 kHz–6 GHz)

	SAR Basic Restriction (W/kg)**	
CONDITION	Uncontrolled Environment	Controlled Environment
The SAR averaged over the whole body mass.	0.08	0.4
The peak spatially-averaged SAR for the head, neck and trunk, averaged over any 1 g of tissue*	1.6	8
The peak spatially-averaged SAR in the limbs, averaged over any 10 g of tissue*	4	20

* Defined as a tissue volume in the shape of a cube.

** Averaged over any 6 minute reference period.

2.1.3 Frequencies from 6 GHz–300 GHz

For frequencies above 6 GHz, energy deposition occurs predominantly in the uppermost layers of superficial tissues (e.g. skin, cornea). In this case, power density is a more appropriate exposure limit metric. Therefore, for the frequency range from 6 GHz to 300 GHz, the incident unperturbed power density and its derived electric- and magnetic-field strengths (assuming a free-space impedance of 377 ohms) form the basic restriction in this safety code (Section 2.2.2) and shall not be exceeded.

2.2 REFERENCE LEVELS

In practice, direct measurements of internal electric fields or SAR are often only feasible under laboratory conditions. Therefore, reference levels are specified in this safety code in terms of external unperturbed electric and magnetic field strength, power density, as well as induced and contact currents. In the far-field zone of an electromagnetic source, electric field strength, magnetic field strength and power density are interrelated by simple mathematical expressions, where any one of these parameters defines the remaining two. In the near-field zone, both the unperturbed electric- and magnetic-field strengths shall be measured, since there is no simple relationship between these two quantities. Instrumentation for the measurement of magnetic fields at certain frequencies may not be commercially available. In this case, the electric field strength shall be measured and used for assessing compliance with the reference levels in this code.

2.2.1 Electric and Magnetic Field Strength (3 kHz–10 MHz)

To ensure compliance with the basic restrictions outlined in Section 2.1, at frequencies between 0.003 MHz and 10 MHz, both the NS- and SAR-based reference levels for electric- and magnetic-field strength must be complied with simultaneously at frequencies where reference levels for both apply.

TABLE 3: Electric Field Strength Reference Levels

Frequency (MHz)	Reference Level Basis	Reference Level (E_{RL}), (V/m, RMS)		Reference Period
		Uncontrolled Environment	Controlled Environment	
0.003–10	NS	83	170	Instantaneous*
1.0–10	SAR	$87 / f^{0.5}$	$193 / f^{0.5}$	6 minutes**

Frequency, f, is in MHz. The precise frequencies at which SAR-based electric field strength reference levels for Uncontrolled and Controlled Environments begin are 1.10 MHz and 1.29 MHz, respectively.

TABLE 4: Magnetic Field Strength Reference Levels

Frequency (MHz)	Reference Level Basis	Reference Level (H_{RL}), (A/m, RMS)		Reference Period
		Uncontrolled Environment	Controlled Environment	
0.003–10	NS	90	180	Instantaneous*
0.1–10	SAR	$0.73 / f$	$1.6 / f$	6 minutes**

Frequency, f, is in MHz.

NOTES FOR TABLES 3 AND 4:

1. * At no point in time shall the RMS values for electric- and magnetic-fields exceed the reference levels with an instantaneous reference period in Tables 3 and 4. In the case of RF fields with amplitude modulation, the RMS value during the maximum of the modulation envelope shall be compared to the reference level.

2. ** For exposures shorter than the reference period, field strengths may exceed the reference levels, provided that the time average of the squared value of the electric or magnetic field strength over any time period equal to the reference period shall not exceed E_{RL}^2 or H_{RL}^2, respectively. For exposures longer than the reference period, including indefinite exposures, the time average of the squared value of the electric or magnetic field strength over any time period equal to the reference period shall not exceed E_{RL}^2 or H_{RL}^2, respectively.
3. Where external electric (at all applicable frequencies) or magnetic (at frequencies at or above 100 kHz) field strengths are spatially non-uniform, comparison to the reference levels shall be made after spatially averaging the field strengths over the vertical extent of the human body. Where comparison is to be made to the reference levels based on NS in Tables 3 and 4, spatial averaging is with respect to the sample values of the field strengths. Where comparison is to be made to the reference levels based on SAR in Tables 3 and 4, spatial averaging is with respect to the square of the sample values of the field strengths.
4. Where external magnetic field strengths are spatially non-uniform and are below 100 kHz, the spatial peak magnetic field strength over the vertical extent of the human body shall be compared to the reference levels in Table 4 (i.e. magnetic field strengths shall not be spatially-averaged at frequencies below 100 kHz).
5. For simultaneous exposure to multiple frequencies and where comparison is to be made to the reference level based on NS, each of the field strength frequency component amplitudes shall be divided by the corresponding field strength reference level for that frequency, and the sum of all these ratios shall not exceed unity. This may be expressed as $\sum (E_i/E_{RL}) \leq 1$ for electric field strength or $\sum (H_i/H_{RL}) \leq 1$ for magnetic field strength.
6. For simultaneous exposure to multiple frequencies and where comparison is to be made to the reference level based on SAR, each of the squares of the field strength frequency component amplitudes shall be divided by the square of the corresponding field strength reference level for that frequency, and the sum of all these ratios shall not exceed unity. This may be expressed as $\sum (E_i/E_{RL})^2 \leq 1$ for electric field strength or $\sum (H_i/H_{RL})^2 \leq 1$ for magnetic field strength.
7. For localized exposure of the limbs, the reference levels for magnetic field strength may be exceeded provided that the basic restrictions in Table 1 are respected within the limbs.

2.2.2 Electric Field Strength, Magnetic Field Strength and Power Density (10 MHz–300 GHz)

To ensure compliance with the basic restrictions outlined in Section 2.1, at frequencies between 10 MHz and 300 GHz, the reference levels for electric- and magnetic-field strength and power density must be complied with.

TABLE 5: Reference Levels for Electric Field Strength, Magnetic Field Strength and Power Density in Uncontrolled Environments

Frequency (MHz)	Electric Field Strength (E_{RL}), (V/m, RMS)	Magnetic Field Strength (H_{RL}), (A/m, RMS)	Power Density (S_{RL}), (W/m^2)	Reference Period (minutes)
10–20	27.46	0.0728	2	6
20–48	$58.07 / f^{0.25}$	$0.1540 / f^{0.25}$	$8.944 / f^{0.5}$	6
48–300	22.06	0.05852	1.291	6
300–6000	$3.142 f^{0.3417}$	$0.008335 f^{0.3417}$	$0.02619 f^{0.6834}$	6
6000–15000	61.4	0.163	10	6
15000–150000	61.4	0.163	10	$616000 / f^{1.2}$
150000–300000	$0.158 f^{0.5}$	$4.21 \times 10^{-4} f^{0.5}$	$6.67 \times 10^{-5} f$	$616000 / f^{1.2}$

Frequency, f, is in MHz.

TABLE 6: Reference Levels for Electric Field Strength, Magnetic Field Strength and Power Density in Controlled Environments

Frequency (MHz)	Electric Field Strength (E_{RL}), (V/m, RMS)	Magnetic Field Strength (H_{RL}), (A/m, RMS)	Power Density, (S_{RL}), (W/m^2)	Reference Period (minutes)
10–20	61.4	0.163	10	6
20–48	$129.8 / f^{0.25}$	$0.3444 / f^{0.25}$	$44.72 / f^{0.5}$	6
48–100	49.33	0.1309	6.455	6
100–6000	$15.60 f^{0.25}$	$0.04138 f^{0.25}$	$0.6455 f^{0.5}$	6
6000–15000	137	0.364	50	6
15000–150000	137	0.364	50	$616000 / f^{1.2}$
150000–300000	$0.354 f^{0.5}$	$9.40 \times 10^{-4} f^{0.5}$	$3.33 \times 10^{-4} f$	$616000 / f^{1.2}$

Frequency, f, is in MHz.

NOTES FOR TABLES 5 AND 6:

1. For exposures shorter than the reference period, field strengths may exceed the reference levels, provided that the time average of the squared value of the electric or magnetic field strength over any time period equal to the reference period shall not exceed E_{RL}^2 or H_{RL}^2, respectively. For exposures longer than the reference period, including indefinite exposures, the time average of the squared value of the electric or magnetic field strength over any time period equal to the reference period shall not exceed E_{RL}^2 or H_{RL}^2, respectively.

2. Where exposure is estimated in terms of power density and for exposures shorter than the reference period, power density levels may exceed the reference levels provided that the time average of the power density over any time period equal to the reference period shall not exceed S_{RL}. For exposures longer than the reference period, including indefinite exposures, the time average of the power density over any time period equal to the reference period shall not exceed S_{RL}.
3. Spatially non-uniform external field strengths or power density can be spatially averaged, provided the sampling scheme applied ensures that none of the basic restrictions are exceeded at spatially-averaged exposures equal to the reference level. If spatial averaging is not applied, the spatial peak field strength shall be compared to the reference levels. In the case of field strengths, spatial averaging is with respect to the squared values of the field strength samples while for power density, spatial averaging is with respect to the power density samples.
4. For simultaneous exposure to multiple frequencies and where exposure is estimated in terms of power density, each of the power density frequency component amplitudes shall be divided by the corresponding reference level for that frequency, and the sum of all these ratios shall not exceed unity. This may be expressed as: $\sum (S_i/S_{RL}) \leq 1$.
5. For simultaneous exposure to multiple frequencies and where exposure is estimated in terms of field strength, each of the squares of the field strength frequency component amplitudes shall be divided by the square of the corresponding field strength reference level for that frequency, and the sum of all these ratios shall not exceed unity. This may be expressed as $\sum (E_i/E_{RL})^2 \leq 1$ for electric field strength or $\sum (H_i/H_{RL})^2 \leq 1$ for magnetic field strength.
6. For pulsed RF field exposures estimated in terms of power density, the time-averaged power density, averaged over any time period equal to the reference period, shall not exceed S_{RL} and the power density, as averaged over the pulse width, shall not exceed 1000 times the reference level, S_{RL}.
7. For pulsed RF field exposures estimated in terms of field strength, the time average of the squared value of the electric or magnetic field strength over any time period equal to the reference period shall not exceed E_{RL}^2 or H_{RL}^2. In addition, the time average of the squared value of the electric or magnetic field strength, as averaged over the pulse width, shall not exceed 1000 times E_{RL}^2 or H_{RL}^2, respectively. Therefore, the RMS electric or magnetic field strength, determined over the pulse, shall not exceed 32 times E_{RL} or H_{RL}, respectively.

2.2.3 Induced and Contact Current (3 kHz–110 MHz)

Induced current is defined as the current flowing through a single foot to ground in a free-standing body (no contact with conductive objects) exposed to an electric field. Where assessment is made of the current flowing through both feet, the result shall be compared to twice the reference level for a single foot.

Contact current is defined as the total current flowing through the body to ground resulting from finger-touch contact with a conductive object insulated from the ground that has been energized in an electric field. Conversely, it can be defined as the total current flowing in an insulated body that has been energized in an electric field and is in finger-touch contact with a grounded conductive object. The current path in the body is from point of touch to ground through the feet. The total current can be assessed anywhere along the path of flow.

TABLE 7: Induced Current Reference Levels

Frequency (MHz)	Reference Level Basis	Reference Level (I_{RL}) through a single foot, (mA, RMS)		Reference Period
		Uncontrolled Environment	Controlled Environment	
0.003–0.4	NS	100 f	225 f	Instantaneous*
0.4–110	SAR	40	90	6 minutes**

Frequency, f, is in MHz.

TABLE 8: Contact Current Reference Levels

Frequency (MHz)	Reference Level Basis	Reference Level (I_{RL}), (MA, RMS)		Reference Period
		Uncontrolled Environment	Controlled Environment	
0.003–0.10	NS	200 f	400 f	Instantaneous*
0.1–10	SAR	20	40	Instantaneous*
10–110	SAR	20	40	6 minutes**

Frequency, f, is in MHz.

NOTES FOR TABLES 7 AND 8:

1. * At no point in time shall the RMS values for induced and contact currents exceed the reference levels with an instantaneous reference period in Tables 7 and 8. In the case of currents with amplitude modulation, the RMS value during the maximum of the modulation envelope shall be compared to the reference level.
2. ** For exposures shorter than the reference period, currents may exceed the reference levels, provided that the time average of the squared value of the current over any time period equal to the reference period shall not exceed I_{RL}^2. For exposures longer than the reference period, including indefinite exposures, the time average of the squared value of the current over any time period equal to the reference period shall not exceed I_{RL}^2.

3. For simultaneous exposure to multiple frequencies and where comparison is to be made to the reference level based on NS, each of the induced- or contact-current frequency component amplitudes shall be divided by the corresponding reference level for that frequency, and the sum of all these ratios shall not exceed unity. This may be expressed as $\sum (I_i/I_{RI}) \leq 1$.
4. For simultaneous exposure to multiple frequencies and where comparison is to be made to the reference level based on SAR, each of the squares of the induced- or contact-current frequency component amplitudes shall be divided by the square of the corresponding reference level for that frequency, and the sum of all these ratios shall not exceed unity. This may be expressed as $\sum (I_i/I_{RI})^2 \leq 1$.
5. For pulsed induced- or contact-currents where a 6 minute reference period applies, the time average of the squared value of the induced- or contact-currents over any time period equal to the reference period shall not exceed I_{RI}^2. In addition, the time average of the squared value of the induced- or contact-current, as averaged over the pulse width, shall not exceed 1000 times the reference level I_{RI}^2. Therefore the RMS value of the induced- or contact-current, determined over the pulse, shall not exceed 32 times the reference level I_{RI}.

ABBREVIATIONS

A	ampere
EEG	electroencephalogram
E_i	electric field strength frequency component amplitude (RMS)
E_{RL}	electric field strength reference level
g	gram
GHz	gigahertz
H_i	magnetic field strength frequency component amplitude (RMS)
H_{RL}	magnetic field strength reference level
ICNIRP	International Commission on Non-Ionizing Radiation Protection
I_i	current frequency component amplitude (RMS)
I_{RL}	current reference level
kg	kilogram
kHz	kilohertz
m	meter
mA	milliampere
MHz	megahertz
mm	millimeter
NS	nerve stimulation
RMS	root mean square
RF	radiofrequency
SAR	specific absorption rate
SI	International System of Units
S_i	power density frequency component amplitude
S_{RL}	power density reference level
V	volt
W	watt

DEFINITIONS

basic restrictions—Maximum allowable internal electrical quantities in the body, arising from exposure to incident external fields, that prevent the occurrence of all established adverse health effects.

contact current—The total current flowing through the body to ground resulting from finger-touch contact with an insulated conductive object that has been energized in an electric field, or from an insulated body that has been energized in an electric field and is in finger-touch contact with a grounded conductive object.

controlled environment—An area where the RF field intensities have been adequately characterized by means of measurement or calculation and exposure is incurred by persons who are: aware of the potential for RF field exposure, cognizant of the intensity of the RF fields in their environment, aware of the potential health risks associated with RF field exposure and able to control their risk using mitigation strategies.

electric field—A vector quantity assigned to any point in space where the magnitude and direction of the force that would be experienced by a hypothetical test charge, is defined.

electromagnetic radiation—A form of energy emitted by accelerating electric charges, that exhibits wave-like behavior as it travels through space.

far-field zone—The space beyond an imaginary boundary around an antenna, where the angular field distribution begins to be essentially independent of the distance from the antenna. In this zone, the field has a predominantly plane-wave character.

field strength—The magnitude of the electric or magnetic field, normally a root-mean-square (RMS) value.

frequency—The number of cycles in the variation of the amplitude of an electromagnetic wave within one second, expressed in units of hertz (Hz).

general public—Individuals of all ages, body sizes and varying health status, some of whom may qualify for the conditions defined for the controlled environment in certain situations.

induced current—The current flowing through one foot to ground in a free-standing human body (no contact with a conductive object) exposed to an electric field.

limbs—Extremities distal from the shoulder and hip joints, which do not include the gonads.

magnetic field—A vector quantity assigned to any point in space where the magnitude and direction of the force that would be experienced by a hypothetical test charge-in-motion, is defined. A magnetic field exerts a force on charges only if they are in motion, and charges produce magnetic fields only when they are in motion.

near-field zone—A volume of space close to an antenna or other radiating structure, in which the electric and magnetic fields do not have a substantially plane-wave character, but vary considerably from point to point at the same distance from the source.

non-thermal effects—Biological effects resulting from exposure to RF fields, that are not due to tissue heating.

power density—The rate of flow of electromagnetic energy per unit area usually expressed in W/m^2 or mW/cm^2 or $\mu W/cm^2$.

radiofrequency (RF)—A rate of oscillation in the range of about 3 kHz to 300 GHz, which corresponds to the frequency of radio waves typically used in radio communications.

reference level—An easily measured or calculated quantity (i.e. externally applied electric field strength, magnetic field strength and power density or resulting body current), that when respected, ensures compliance with the underlying basic restrictions in Safety Code 6.

reference period—A time period used for averaging temporally non-uniform RF field exposures, for comparison with the exposure limits in Safety Code 6. The reference periods specified in Safety Code 6 are based upon the established adverse health effects to be avoided and the time required for those responses to occur. The reference period is not a maximum exposure time.

RMS (root mean square)—As applied to a set of data, it is the square root of the average of the square of the data values.

safety—The absence of established adverse health effects caused by RF field exposure.

specific absorption rate (SAR)—A measure of the rate at which energy is absorbed by the body (or a discrete tissue volume) when exposed to a radiofrequency (RF) field. SAR is expressed in units of watts per kilogram (W/kg), and can be calculated from the product of the tissue conductivity (S/m) and the square of the RMS electric field strength induced in the tissue (V/m), divided by the mass density (kg/m^3) of the tissue.

thermal effects—Biological effects resulting from heating of the whole body or of a localized region due to exposure to RF fields, where a sufficient temperature increase has occurred that results in a physiologically significant effect.

uncontrolled environment—An area where any of the criteria defining the controlled environment are not met.

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